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Bait placement and acceptance by rats in macadamia orchards

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Black rats (*Rattus rattus*) cause extensive damage in Hawaiian macadamia (*Macadamia integrifolia*) orchards. Many growers apply rodenticides to reduce rat populations in orchards, but improper placement of bait may reduce the effectiveness of many baiting programs. We evaluated the optimum placement of bait in macadamia orchards among the three locations specified on current rodenticide labels. We placed a non-toxic oat bait treated with 0.75% tetracycline hydrochloride, an antibiotic that chelates with calcium in growing bones and teeth and fluoresces under UV light, in burrows, on the ground and in trees in separate orchard sections. We consistently captured the greatest percentage of marked rats (53–91%) in sections where we placed the bait in trees and the lowest percentage of marked rats (0–36%) where we broadcast bait on the ground. Placement of bait in burrows produced intermediate results (40–70%). These results suggest that broadcasting bait on the orchard floor reduces the effectiveness of rat control programs. Placing baits in trees targets rats that not only are most likely to eat the poison bait, but also are most likely to damage developing nuts. Published by Elsevier Science Ltd

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Introduction

Application of rodenticides often is the most practical, economic and effective method of reducing economic (Dubock, 1984), health (Gratz, 1988) and ecological (Moors *et al.*, 1992) problems caused by rodents (Jackson, 1987; Myllymäki, 1987). Many rodenticide baiting programs fail, however, because of neophobia, bait shyness, improper bait placement or resistance (Barnett, 1988; Prakash, 1988).

Black rats (*Rattus rattus*) cause extensive nut damage in Hawaiian macadamia (*Macadamia integrifolia*) orchards (Ooka, 1968, 1976; Fellows, 1982; Tobin *et al.*, 1993). Most damage is inflicted to developing nuts. Application of rodenticides is the most commonly used method for reducing rat populations and associated nut damage in Hawaiian macadamia orchards. Registration labels allow baits to be placed in burrows, put in bait stations in trees or on the ground, or broadcast on the ground. Growers typically choose the latter option because it is the fastest and least labor-intensive. However, broadcast applications may not be effective in macadamia orchards.

Recent studies indicate that rats in macadamia orchards spend little time on the ground and thus may not consume bait placed there. Traps set on the orchard floor consistently capture fewer rats than do traps set in trees (Tobin *et al.*, unpublished data). In a recent radio-telemetry study of daily and seasonal movements and activity of rats in a macadamia orchard, rats spent all of their active hours in the canopy (Tobin *et al.*, 1996b). In a subsequent small-scale test, 11 radio-telemetered rats all survived a broadcast application of zinc phosphide oats (Tobin *et al.*, unpublished data).

To determine whether placement of bait in macadamia orchards influences acceptance by black rats, we evaluated the relative consumption of non-toxic bait placed in each of three locations specified on registration labels for applying rodenticides in macadamia orchards: in burrows, on the ground or in trees. Our objective was to determine the optimum location for applying rodenticide baits in macadamia orchards.

Materials and methods

Study areas

We conducted the study from May 1994 through June 1995 in three regions on the island of Hawaii: Kau Agribusiness, Inc.'s orchard in Keaau, 17 miles south of Hilo; Kapulena Orchards in the Hamakua district on the northeastern side of the island; and three small orchards between Captain Cook and

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Honaunau in Kona on the drier western side of Hawaii island.

The Keaau study sites comprised three 10-ha orchard sections that were 120 m in elevation and contained 20-year-old macadamia trees. On one side the orchard sections were separated from an ornamental crop by a 10-m strip of Norfolk Island pine trees and other non-crop trees. On the other three sides, the study sections abutted a windbreak of Norfolk Island pine trees separating them from other similar orchard sections. The orchard floor consisted mostly of bare soil and lava rock.

The Hamakua study sites comprised two 20-year-old orchard sections of about 10 ha each that ranged from 600 to 800 m in elevation. The sections were elongated and irregularly shaped, varied in width from about 25 to 100 m and were interspersed with intermittent patches of non-crop vegetation. The orchard floor consisted of bare soil with occasional patches of weedy ground vegetation or rock outcroppings

The Kona sites encompassed three orchards that varied in size from 2 to 4.5 ha, ranged in elevation from 800 to 2400 m and were typical of the smaller macadamia orchards on the western side of Hawaii island. The macadamia trees ranged from 25 to 40 years of age. The orchard substrate consisted mostly of bare soil interspersed with rock outcroppings and occasional interplantings of coffee trees.

Bait preparation

We prepared non-lethal baits with 0.75% tetracycline hydrochloride (THC) (Schweizerhall, Inc., South Plainfield, NJ, USA) and 2% (g/g) Alcolec-S (American Lecithin, Atlanta, GA, USA). We coated oat groats (Honeyville Grain, Inc., Honeyville, UT, USA) with approximately 1/2 of the Alcolec-S, mixed it for 5 min, added the THC, mixed it for an additional 5 min and inspected the oats under a long-wave (3150–4000 Å) UV light to confirm that the THC was distributed uniformly. We then added the remaining Alcolec-S and mixed the final bait for an additional 5 min (Tobin *et al.*, 1996a) before spreading the bait over several aluminum trays and allowing it to dry in an air-conditioned dark room. We stored the bait in double opaque plastic bags until we applied it in the field study.

Bait application

We used a randomized block design to apply all three treatments in each region except Hamakua, where a lack of visible burrows precluded this treatment. We applied one treatment at each site by using a plastic soup spoon to place 13–15 g of oat groats in every burrow entrance (276 at Keaau and 217 at Kona), in the crotch of a lower lateral branch of every tree (1844 at Keaau, 187 at Hamakua and 125 at Kona) or on the ground under every tree (2333 at Keaau, 624 at Hamakua and 323 at Kona), depending on the assigned treatment. For the latter treatment, we broadcast the bait around the base of the tree. We did not apply bait in non-crop areas surrounding the orchards.

Trapping

Thirteen to 18 days after applying the bait in each orchard, we placed one rat snap trap (Woodstream Corporation, Lititz, PA, USA) on a lower lateral branch in every tree and another trap on the ground under every tree to capture a representative sample of rats in the orchard. We did not place traps at burrow entrances because a previous study (Tobin *et al.*, 1996b) indicated that rats in Hawaiian macadamia orchards, even those utilizing burrows, forage primarily in trees and thus are likely to encounter traps placed at the base of trees and in lower branch crotches. To determine the extent to which rats in surrounding areas forage in the orchards (and thus are likely to consume baits applied in the orchards), we placed traps on the ground in adjacent non-crop areas at the Hamakua and Kona sites; the Keaau study sites were surrounded mostly by other similar orchards. We prebaited the traps with grated coconut 3–5 days before baiting them with chunks of coconut and setting them for four consecutive nights. We checked the traps daily, removed carcasses for later inspection and rebaited and reset the traps as necessary.

Examination of carcasses

We examined the exposed portion of the incisors of each captured rat under a long-wave UV light for fluorescence. If no fluorescence was observed on the exposed portion of the incisors, we extracted the lower mandible, boiled it in water and removed the flesh and incisors. We examined the mandibles and basal portion of the incisors under a UV light to detect fluorescence at the growing points.

Statistical analyses

We used Fisher's exact test to detect differences among treatments in the proportion of rats captured that exhibited the fluorescence characteristic of THC consumption. Because all treatments were not applied at all locations, we evaluated the three regions separately.

Results

The proportion of captured rats that were marked varied among treatments ($P<0.001$) in all three regions (*Table 1*). We consistently captured the greatest proportion of marked rats in orchard sections where we placed the bait in trees (Keaau 91%, Hamakua 53% and Kona 61%) and captured the lowest percentage of marked rats where we broadcast the bait on the ground (Keaau 36%, Hamakua 5% and Kona 0%). Placement of bait in burrows produced intermediate results (Keaau 70% and Kona 40%). This trend among treatments held regardless of whether rats were captured within the orchard or in adjacent untreated non-crop areas (*Table 1*). The lower percentage of marked rats from non-crop areas adjacent to the orchards indicates that

Table 1. Percentage of rats (*Rattus rattus*) (number captured in parentheses) in Hawaiian macadamia orchards or adjacent non-crop areas that ingested non-toxic oat bait treated with 0.75% tetracycline hydrochloride. Bait was distributed in orchards by placing it in trees, putting it in burrows or broadcasting it on the ground under trees

Region	Capture location	Bait placement		
		Tree	Ground	Burrow[a]
Keaau	In orchard	91	36	70
		(56)	(44)	(30)
	Non-crop[b]	—	—	—
Hamakua	In orchard	79	11	—
		(24)	(9)	—
	Non-crop	38	0	—
		(42)	(11)	—
Kona	In orchard	70	0	57
		(83)	(48)	(35)
	Non-crop	36	0	6
		(28)	(10)	(17)

[a]A scarcity of burrows precluded evaluation of this bait placement at Hamakua. [b]The Keaau study sites were surrounded mostly by other similar orchard sections.

only some of the rats ventured into the orchards to forage during the study.

Discussion

Placement of bait in macadamia orchards clearly influences acceptance by black rats. That the proportion of rats that consumed bait was greatest where the bait was placed in trees is consistent with our observation that rats in Hawaiian macadamia orchards forage mainly in the canopy and spend little time on the orchard floor, even where they utilize underground burrows (Tobin *et al.*, 1996b). Burrow baiting was not as effective as placing bait in trees, but it provides an alternative means of applying bait when tree baiting is not feasible, such as when bait stations are unavailable or impractical.

We predicted that rats in Hamakua and Kona would spend more time on the ground and thus consume more broadcast bait than rats in Keaau because of differences in orchard substrate and the proximity and abundance of non-macadamia vegetation. The Keaau orchard sections were almost completely devoid of ground vegetation and it is not surprising that few rats consumed bait from the ground. The long and narrow Hamakua orchard sections were also mostly devoid of non-macadamia vegetation, but adjacent non-crop vegetation was within 30 m of most interior macadamia trees. The macadamia trees in the Kona orchards were interplanted with coffee, banana, mango and/or avocado trees that might have provided cover for rats to spend more time on the ground. The consistently low consumption of bait broadcast on the ground, in spite of these differences, calls into question the effectiveness of current rat control programs that broadcast rodenticide baits on the orchard floor.

Costs of application should be considered when deciding how to distribute rodenticide baits. The relatively low cost and ease of mechanically broadcasting baits makes this an attractive alternative. However, poor bait acceptance greatly reduces the cost-effectiveness of this technique. Placing bait in burrows usually requires less bait than mechanically broadcasting bait but is more labor-intensive because of the difficulty of locating and treating every burrow. This technique probably would not be cost-effective for large orchards. Placing bait in trees also is labor-intensive but requires less searching than burrow baiting. Current rodenticide labels require the use of bait stations to minimize exposure of non-target animals to rodenticides placed in trees. Further research is needed to evaluate consumption of bait from stations placed in trees. Any increased expense associated with bait stations could be prorated over the expected life of the bait stations. Furthermore, managers probably need not place a bait station in every tree but only at ≥ 5 locations/ha to make bait available to all rats in an orchard (Tobin *et al.*, 1996b). The increased expenses associated with tree baiting would probably be more than offset by the benefits not only of maximizing consumption but also of targeting rats that are most likely to damage developing nuts.

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